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IT has happened again and again in the history of discovery that some of the most important advances in a particular science have been made by persons not engaged in the professional pursuit of that subject.

No doubt the formal recognition of public health as a science is of quite recent date, but there have always been those who have recognized the paramount claims of that branch of knowledge now embodied as hygiene or preventive medicine. Medical men, as might be expected, have in all ages been interested in measures that tended to the health of the community as distinguished from that of the individual merely. But persons who were not medical men at all have from time to time either made suggestions of permanent value as touching the health of the people, or, going farther, have actually made contributions to the science of public health of such a kind that without these progress in that science would have been very greatly delayed. The truth of this is strikingly brought out in the life of one of the name of Hales, a clergyman of the Church of England, a man who had neither studied medicine nor taken a medical degree, but who was, nevertheless, the first person in England to make any serious attempt to provide for the systematic supply of fresh air to places where impure air could not leave by natural means. The Reverend Stephen Hales, M.A., D.D., F.R.S., was *the* pioneer in the hygiene of ventilation.

There have been parallel cases in other sciences: the Marquis of Worcester, though not an engineer, invented the steam pump; Leeuwenhoek, though not a member of the medical profession, made discoveries of the most fundamental order in physiology and microscopical anatomy; Captain Cook, though neither a physician nor a biologist, investigated from the practical side the causes and incidence of scurvy with such excellent results to the health of sailors that he was awarded the Copley medal of the Royal Society in 1776; Lady Mary Wortley Montagu, the wife of the British ambassador at Constantinople, introduced inoculation for smallpox into England; Helmholtz, though not an oculist, invented the ophthalmoscope; Pasteur, though not a medical practitioner, introduced inoculation of attenuated virus for the cure of hydrophobia; and, in our own day, Metchnikoff, trained as a scientific zoologist, has exercised a most far-reaching influence on the doctrines of bacteriology and practical medicine.

Mankind did not arrive apparently by the aid of "the light of nature" alone at a knowledge of the supreme importance of ventilation. To *some* results of great practical importance, purely natural instincts have guided mankind; for there are certain things known to be poisonous when eaten, certain waters are declared non-potable; but, as regards the quality of the air to be breathed and what constitutes impure air, the natural teachings are exceedingly ambiguous. The natural man is all right so long as he remains under the open heaven, but as soon as he surrounds himself with four walls he seems not to know that he must constantly keep changing the invisible air around him. No doubt it is because it is out of sight that air is also out of mind: certain it is that at the present moment there are vast multitudes of people who never conceive of air as a real thing, as real as their meat and drink and just as necessary to be kept fresh. Cave-man had no trouble with ventilation, nor had those in "the tents of Shem"; but from the day that man began to sleep inside stone and lime he had to face the problem, although he was not in the least conscious of it, how could the foul air be removed and the pure air brought in without producing a chilling draught. To do this is to ventilate. The unpleasantness and even danger to health of this movement of the air was, doubtless, much of the reason why he was so long in grappling with the problem even when he had awakened to its existence. Not that he has even now by any means consciously solved the problem. There are millions of houses over the length and breadth of the earth entirely unprovided with the means of ventilation; heated they may be, ventilated they are not. With their closed stoves and their windows shut, such rooms are as devoid of the means of changing the air in them as is an oven. The least fresh of rooms in England with their open chimney, even when no fire is burning, and with "sash" windows capable of being easily opened from the top without causing a draught, may be said to be exceedingly well ventilated as compared with the typical room one finds on the Continent of Europe. All living things vitiate air on breathing it even once; all living things subsist by means of the absorption of oxygen, that is, of fresh air: this was what Hales grasped, and he saw how very far many members of the community were from being in a position to command at all times a supply of this absolutely necessary though perfectly invisible material. Hales in England and Leeuwenhoek in Holland, neither of them medical men, were, about the year 1720, probably the two persons who saw more clearly than any one else in Europe the prime necessity for ventilation, that is, the constant change of the air in the neighborhood of living beings.

Hales did a very great deal else in science besides devising ventilators; he was a pioneer in the experimental method in both vegetable and animal physiology quite a hundred years before physiology as an experimental science existed in England. But in regard to the public

health it is not too much to say that as a benefactor of mankind, he is conspicuous in the first half of the eighteenth century. It would be difficult to mention the name of any other person co-equal with his. We know very little indeed of his capabilities as a pastor of men's souls, but it is certain that he had great solicitude for their bodies; he introduced a water-supply into the village of Teddington, and it appears that he actually contrived to ventilate its parish church. His pamphlet against the abuse of alcohol is probably the first of its kind in English—"A friendly admonition to the drinkers of gin, brandy and other spirituous liquors." This, published in 1734, alone enables him to rank as a pioneer in the advocacy of measures of practical hygiene. Hales had grasped the very essence and kernel of the principle of ventilation, *that air must be changed,* whether air for plants or for animals, air over corn in granaries or over water stored for drinking purposes or air enclosed in hot-houses, or air in mines, or in the holds of ships, or in prisons, or around timber or gunpowder; air must be changed. He knew that fresh air was inimical to putrefaction, mouldiness of every kind; he invented an apparatus for blowing air through drinking water stored in ships. On long voyages in the "old wooden walls" such water became putrid: Hales showed that it could be made sweet again if only enough air could be blown through it. We *now* know what was going on, namely the oxidation of organic matter; but Hales died in 1761, thirteen years before oxygen was discovered. It is interesting to note that Hales had the most definite conceptions as regards this necessity for oxygen in ventilation, without knowing what it was that sustained life, and without knowing, in anything like its fulness, the meaning and importance of Joseph Black's discovery that animals exhaled carbon dioxide from their lungs. Black's discovery was published in 1754, some seven years, indeed, before Hales died; but it is certain that Hales was not indebted to Black; on the contrary, it is not as widely known as it might be that Black was profoundly indebted to Hales. Black wrote:

> I was partly led to these experiments by some observations by Dr. Hales, in which he says that breathing through diaphragms of cloth dipped in alkaline solution made the air last longer for the purposes of life.

Before we further examine the value of the contributions made by Hales to the hygiene of ventilation, it will be well to trace the order of the discoveries of the gases of the atmosphere without which, of course, in the long run no scientific basis for the study of the problems of ventilation could have been arrived at. Carbon dioxide was discovered under the name of gas sylvestre by the Belgian chemist J. B. van Helmont (1577 to 1644) about the year 1640. Having burnt a known weight of wood, he noticed that only about one sixtieth of the original weight remained in solid form. The other fifty-nine sixtieths he regarded as

something volatile to which he gave the name of "gas," a word he coined on purpose to designate this "spirit" of wood and other kindred spirits. Gas sylvestre, because it came from or was produced by the burning of wood, was the first name under which carbon dioxide became a chemical concept in the minds of men of science.

The next contributions to accurate notions about breathing and hence about the necessity of ventilation, were made by Thomas Willis (1621 to 1675), who distinctly laid it down that three things cooperated in the act of respiration. These were: (1) a free and continuous access of air; (2) a constant supply of combustible material, and (3) the necessity for the continuous removal of the products of the combustion, for Willis clearly identified the burning of a flame in air and respiration in a living animal body; it is certain that he believed that they were chemically the same thing. It was in 1660 that the Hon. Robert Boyle, who did so much for the early mathematico-physical study of the atmosphere and of gases, performed the fundamental experiment as regards ventilation, namely, to exhaust the air around a living animal. He showed that long before the vacuum was perfect, a sparrow and a mouse had both died, and the flame of a candle had gone out. Boyle also understood that there was something besides watery vapor that rendered expired air unfit for further breathing by animals. G. A. Borelli about twenty years later was the first to estimate what we now know as the "tidal air," that is the quantity of air taken in and sent out at each breath, a most important datum as regards the supply of fresh air per person.

The Cornishman, Richard Lower, clearly perceived before 1669 that the blood in the lungs was arterialized by absorbing something from the inspired air, what we now know to be oxygen. Lower was also quite certain that the expired air was noxious and ought to be removed; were there no need for this change, he writes, "we should breathe as well in the most filthy prisons as amongst the most delightful pastures." Lower held it as an axiom that where a fire burns readily, there an animal can breathe easily. The full significance of Lower's conclusions was not grasped by his contemporaries; even so great a physiologist as Haller failed to see all that they involved.

The next step was taken also by an Englishman, an Oxford man of science, John Mayow. Working between 1668 and 1674, Mayow virtually discovered oxygen in a physiological sense. He named it "nitro-aerial particles," for he identified the substance which, absorbed from the air in breathing, produces animal heat, with the substance niter that appeared to be the cause of the combustion of gunpowder. Mayow died in 1679; and in England nothing was done as regards respiration or ventilation until Hales arose to rediscover much that Lower and Mayow had known well. In some respects Hales was less of a chemist than Mayow, but he caused hygiene to advance to a vastly greater ex-

tent because he applied what little theoretical knowledge he had to the solving of problems of very definite practical utility. He knew something of the work of his predecessors Borelli, Lower and Mayow. He knew that of his contemporary Boerhaave; but, much less technically learned than all of these, he became the pioneer sanitarian of the first half of the eighteenth century. He was not a physiological chemist like Lower and Mayow, but he was the discoverer of a method of sustaining respiration in the absolutely irrespirable atmospheres of coal-mines or burning houses. He suggested that the apparatus might be serviceable for divers. He was the father of all such as descend into "fire-damp" and "choke-damp" and "black damp" provided with an independent supply of air in an apparatus capable of absorbing the exhaled carbon dioxide. He was the Jubal of all such as handle rescue-apparatus. He was a pioneer in a great deal else that does not concern us now, for he was the first person in this or any other country to obtain by experiment on the living animal a demonstration of the magnitude of the pressure of the blood in arteries; and he is the father of vegetable physiology in England, and he is much else. But we must not imagine that, although Hales devised an artificial respiration apparatus, he was acquainted with all the properties of carbon dioxide. For just as Van Helmont in the seventeenth century worked with the carbon dioxide of combustion without being aware of all its properties, so Hales in the eighteenth worked with the carbon dioxide of respiration without realizing all that was involved in his researches. This sort of thing has happened again and again in science. Respiratory carbon dioxide was discovered by Professor Joseph Black at the University of Glasgow in 1754. In point of time nitrogen was the next constituent of the atmosphere to be identified: this was also by a Scotsman, Professor Daniel Rutherford (1749–1819) of the Chair of Botany at Edinburgh. The year of this was 1772, the man the maternal uncle of Sir Walter Scott. Within two years more, oxygen was separated by Joseph Priestley from mercuric oxide under the name of "dephlogisticated air." By 1775 Priestley had found that this gas supported both combustion and respiration. Had it not been for the phlogiston theory, to which he clung with fatal tenacity, Priestley would have been the undisputed discoverer of the gaseous basis of life; as a matter of fact, Lavoisier, as we are all aware, was the man who knew what he had got when by the end of 1774 he had isolated *oxygen* and so named it.

But we must not forget that Priestley also worked much on the properties of carbon dioxide, it was the gas he first studied near a brewery at Warrington. As early as 1772 he read a paper to the Royal Society showing experimentally that, while animal life could not be supported by this gas, plants, on the other hand, restored the wholesomeness to air rendered putrid by animal breathing. He also demonstrated that by both combustion and respiration the air loses one

fifth of its volume: for these researches Priestley received the Copley medal in 1773.

The details of the private life of Stephen Hales are neither numerous nor romantic. The son of Thomas, eldest son of Sir Robert Hales of Beckesbourn, Stephen was born in 1677 near the pleasant village of Beckesbourn in Kent, not far from Canterbury. His mother was Mary, daughter and heiress of Richard Wood, of Abbot's Langley. At the age of nineteen he went to Cambridge, being entered at Bene't College (now Corpus Christi), of which he became a fellow in 1703. In due time he graduated M.A. and he took his B.D. degree in 1711. His early scientific leanings may be inferred from his having studied anatomy, chemistry and botany as a recreation. Accompanied by William Stukeley, a fellow student, later M.D. and F.R.S., Hales is reported to have studied field botany on the Gog-Magog Hills and on Cherry Hunt Moor by the aid of Ray's catalogue of local plants, and also at this time to have made collections of fossils and of butterflies. It was as a student, too, that he contrived to make a cast in lead of the lungs of a dog. He did not neglect astronomy, for according to one account he constructed a "planetarium in brass" or, as it was later called, an "Orrery" on Newtonian principles. Having taken Holy Orders, Hales was presented in 1710 to the "perpetual curacy" of Teddington in Middlesex. Not long after he resigned his fellowship on being presented to the living of Porlock in Somerset; this he finally exchanged for that of Farringdon in Hampshire. The date of his marriage is uncertain: it is thought to have been in 1719; his wife died childless in 1721; Hales did not marry again. It was at Teddington that by far the greater number of his experiments were carried out. At his own expense he rebuilt the tower of the parish church of St. Mary's-in-the-Meadows. In 1718, at the comparatively early age of forty, Hales was elected into the Royal Society, and twenty-two years later was awarded the Copley medal—the highest honor in the gift of that learned body. Until within a year or two of his death he communicated the results of his manifold researches in the form of papers to the Royal Society. He published, however, in book form several treatises: his "Vegetable Statics" saw the light in 1726, and the "Hæmostatics" or Volume II. in 1733. Volume I. is dedicated to "His Royal Highness George Prince of Wales" and Volume II. "To the King's Most Excellent Majesty." This "George, Prince of Wales," and the "King's Most Excellent Majesty" are the same person, for in 1726 George I. was still reigning, but by 1733 his son George, who had been Prince of Wales, was now George II.

Although, then, Hales wrote extensively on vegetable and animal physiology, chemistry and medicine—for he discoursed on the alleged virtues of tar-water and investigated solvents for stone in the bladder—it is as a pioneer sanitarian that he must ever live in our grateful

remembrance. He did not occupy his time in calculations as to the number of cubic feet of air required per person per hour, but he designed a workable apparatus on the principle of the bellows for the purpose of abstracting air from places particularly badly situated as regards the changing of their air. The earlier forms were worked by hand, the later were driven by a windmill, their general design being much the same as that of bellows for church-organs. The velocity of outflow of air from the bellows, Hales expresses as 6¼ miles an hour, a little over 9 feet per second.

His first paper on the importance of ventilators in mines, hospitals, prisons and ships was read to the Royal Society in 1741, in which year an almost identical invention was announced by one Martin Friewald, "captain of mechanics" to the King of Sweden. So useful was this latter apparatus that the French government ordered an installation of it on all the ships of their navy. Not once or twice in the story of invention have important discoveries been made simultaneously and often in countries widely distant, as in the present instance. The title-page of the treatise in which Hales describes his invention reads thus:

> A description of Ventilators whereby great quantities of fresh air may with ease be conveyed into mines, gaols, hospitals, workhouses and ships in exchange for their noxious air, and in preserving all sorts of grain dry, sweet and free from being destroyed by weevils both in granaries and ships . . . as also in drying corn, malt, hops, gunpowder &c and for many other useful purposes which was read before the Royal Society in May 1741.

Truly it was not an age of succinct titles, but its length enables us to see that Hales had a clear idea of that one thing needful, namely, fresh in place of noxious air; he was under no doubt whatever that the air of mines, gaols, hospitals, workhouses and ships, left to itself, becomes noxious and must be changed. This is corroborated by the quotation from Milton which follows:

> and God made
> The firmament expanse of liquid, pure
> transparent, elemental air.

In this work he speaks of "the rancid vapors from human bodies"; from this it is not quite clear whether or not Hales was distinguishing respiratory carbon dioxide from the noxious vapors arising from the skin and lungs. We must at any rate remember, as has been already said, that he wrote without knowing of the discovery of respiratory carbon dioxide. It is certainly interesting to be told the very latest opinion as to the deleterious nature of breathed air is that it is not due to the carbon dioxide *per se,* but that the headache and distress are due to the moisture, the heat and the disagreeable, volatile, organic effluvia from the skin and lungs of the persons within the confined space. Without any technical chemical knowledge of the precise cause of impure air, Hales had grasped the far more important fact that

breathed air must be got rid of and sent outside into the ocean of the atmosphere.

It can not in fairness be alleged that those in authority were slow to avail themselves of the benefits of Hales's ventilators; but their adoption in the prisons, where the ventilation was excessively bad, was no doubt hastened by the deaths of the Lord Mayor of London, two Judges and an Alderman, all of whom became infected with gaol fever caught at the Old Bailey Sessions. "The Royal Society," wrote the late Sir William Huggins, "was called upon for advice and assistance. A committee was appointed to investigate the wretched state of ventilation in gaols. A ventilator invented by one of the committee was erected in Newgate, reducing at once the number of deaths from eight a week to about two a month. Of the eleven workman employed to put up the ventilator, seven caught the fever and died." There is not the slightest doubt that in those days to be sent to prison was the same thing as undergoing the death sentence of poisoning by foul air. Though Huggins does not mention Hales, it is certain he is the person alluded to as on the committee who introduced his ventilators into the prison. The version given by Peter Collinson in his sketch of the life of Hales (*Annual Register* for 1764) differs a little in one or two particulars: this writer states that in 1749 Hales's ventilators were installed in the Savoy prison by order of Mr. Henry Fox, later the first Lord Holland. Between the years 1749 and 1752 four prisoners died there of gaol fever as compared with between fifty and a hundred per annum previously. In the year 1750, out of two hundred and forty prisoners, only four died; and of these two died of smallpox and one of alcoholism, so that the salutary effects of Hales's installation were immediate and striking. In 1752 his ventilators actuated by a windmill and having ducts leading from twenty-four cells or wards were introduced into Newgate prison: as a result of this, Collinson says, the ratio of deaths after to those before the ventilation was as seven to sixteen, that is they had been reduced to less than 50 per cent. In 1753 Hales wrote an article in the *Gentleman's Magazine* on the applicability of his ventilators to army hospitals and to private houses. He also reported on their means in a smallpox hospital. Before his death his ventilators had been installed in the prisons at Winchester and Durham. In modern terminology, Hales ventilated by abstraction of foul rather than by propulsion of fresh air.

Hales's invention was greatly appreciated on board ship. Ships at this time were floating strongholds of death; between scurvy and ship fever due to poisoning by bad air, only the most robust men survived for any length of time. In 1755, Hales wrote a short but most interesting paper to the Royal Society, entitled "An account of the great benefits of ventilators in many instances in preserving the health and lives of people in slave and other transport ships." In this, Hales

speaks of "finding means to procure them fresh, salutary air instead of the noxious, putrid, close, confined, pestilential air which has destroyed millions of mankind in ships." He says "the principal cause of the sickness in ships is the noxious, putrid air; the obvious remedy is the exchanging that foul air for fresh by effectual means which are seldom discovered by dwelling only on objections." Hales further alludes to the "vulgar, false and groundless notion that they take up too much room . . . the men are eager to work them."

"Decay," he continues, "is wholly owing to damp, close, confined, putrid, corroding air, so the only remedy for this evil is the frequently changing the air among the timbers by plentiful ventilations." Hales published in this paper a letter dated London, September 25, 1749, from a Captain Thomson of the frigate *Success* which is most interesting reading:

> Our rule for ventilating was half an hour every four hours, but when the ventilating was sometimes neglected for eight hours together, then we could perceive, especially in hot weather, a very sensible difference by the neglect of it. All agreed the ventilators were of great service. The men did not need to be urged to work them. Two hundred men aboard for a year, pressed men from gaols, with distemper all landed well in Georgia. This is what I believe but few transports or any other ships can brag of, nor did I ever meet the like good luck before, which, next to Providence, I impute to the benefit received by the ventilators. . . . This certainly occasioned all kind of grain provisions to keep better and longer from weevels than otherwise they would have done, and other kinds of provisions received benefit from the coolness and freshness in the air of the ship which was caused by ventilation.

Hales then quotes a Mr. Cramond, who attributed the good health of his ship with three hundred and ninety-two slaves and Europeans, to the presence of the ventilators; twelve of the slaves died, but when taken on board they were all "ill of a flux." The next report is from a Captain Ellis, writing from Bristol, December 26, 1753. After lamenting the *vis inertiæ* of prejudice and ignorance, Ellis says:

> ''It does honour to those noble and other worthy personages that join you in acts of such extensive humanity as the introduction of ventilators to hospitals, prisons, ships of war and transport &c as they necessarily render the miseries of the first more supportable, and the close and constant confinement of the others less prejudicial and fatal to their health and life.
>
> The ventilators were of singular service to us, they kept the inside of the ship cool, sweet, dry and healthy. The number of slaves I buried was only six, and not one white man of our crew (which was thirty-four) during a voyage of fifteen months, an instance very uncommon. The three hundred and forty negroes were very sensible of the benefits of a constant ventilation, and were always displeased when it was omitted.''

Captain Ellis did better still in his next voyage in 1755, for not one of the three hundred and twelve slaves died, and these and all his crew to the number of thirty-six were landed alive and well at Bristol. Hales goes on to say that the Earl of Halifax (1716–1771)

told him of the great benefit derived from ventilators installed in transport-ships to Nova Scotia; the deaths in ventilated to those in non-ventilated ships being as one to twelve. Through soliciting the interest of the French man of science du Hamel de Monceau, Hales contrived to have his ventilators installed in certain prisons in France where English prisoners were confined. He jokingly said that he hoped that he would not be accused of assisting the enemy. The reverend sanitarian closes his paper with these words:

> They little consider that it is the high degree of putrefaction (that most subtle dissolvent in nature) which a foul air acquires in long stagnating which gives it that pestilential quality which is called the gaol-distemper, and a very small quantity or even vapour of this highly attenuated venom like the infection or inoculation for smallpox soon spreads its deadly infection. Ought not men therefore . . . to use their utmost endeavours to shun this pestilential destroyer by which millions of mankind have perished in ships.

Now this is a somewhat remarkable paragraph to have been written in 1755. It undoubtedly refers to typhus fever, known under all the following names: putrid fever, pestilential fever, ship fever, emigrant fever, hospital fever, and gaol fever. It was, for it is happily now quickly disappearing, the fever of bad sanitation, the scourge of unwashed, ill-fed, badly housed, neglected specimens of humanity. Even now its precise cause, whether coccus, bacillus or other parasite, is not known. The very latest suggestion is that it is an ultra-microscopical virus transmitted by some insect that infests persons of unclean skins. But the very fact that to-day we have not isolated the virus is a sufficient proof of its excessively elusive nature—a very attenuated poison indeed, as Hales says. Of course Hales did not know it as typhus fever: typhus, typhoid and relapsing fever were all confused until Sir William Jenner about 1850 clearly distinguished between the first two. With the rise of bacteriology, the microorganic origins of the last two have been established; the true cause of typhus has still to be discovered. While pathologists are still struggling over the precise cause of this fever, the practical sanitarians have almost banished it from Great Britain. Better feeding, more facilities for personal cleanliness, and above all a clearer appreciation of what ventilation means have cooperated in abolishing this horrid scourge; but let us never forget that the initial, intelligent stages of the war against it were undertaken by Stephen Hales.

Amongst other analyses Hales made was the analysis of the expired air. He evidently regarded death in explosions in mines and of the animals in the "grotto di cani" as being due to the same poisonous gas.

Besides attacking and solving the problem of ventilating such places as most urgently needed it, Hales devised a method whereby a person could enter an irrespirable atmosphere and continue to breathe,

if not absolutely pure air, such air as could sustain life for some minutes, long enough to enter a burning house or, as he suggested, a laboratory filled with noxious fumes. The mechanism was a bladder divided up into compartments by four diaphragms of flannel or linen soaked in a solution of potash or "sal tartar" capable, as we now know, of absorbing the respiratory carbon dioxide. A tube led from the far end of the bladder and, curving upwards, terminated in a mouthpiece near which were placed two valves, one allowing air to enter the near end of the bladder, the other preventing it from passing back into the far end. The nostrils had to be closed, as they have to be in all mouth-breathing forms of such apparatus. The receiver held between four and five "quarts of air"; Hales thought that with one gallon of air and four diaphragms, respiration could be supported for at least five minutes. He remarks, what we can readily believe, that there was much discomfort unless the valves worked easily.[1]

In view of the prominence which life-saving apparatus has attained at the present day, it seems exceedingly interesting to know that before 1726, a practical attempt had been made to construct an artificial rescue-apparatus. Hales himself contemplated its use not only in the foul air of mines, but by divers under water; it is, however, very doubtful whether the mechanism as he left it could have been used under water. This simple invention is the humble parent of the various ingenious life-saving apparatuses of the present day, the Fleuss, the Dräger, and others which enable a man to remain for upwards of two hours in atmospheres not merely poisonous, but actually deadly. As we have already seen, it was this invention of Hales that inspired Black to discover respiratory carbon dioxide.

As all men of science know, Stephen Hales may be said to have founded the science of experimental, botanical physiology; his observations by means of mercury manometers on the pressure exerted by the rising of sap in vines are classical. Although he was a pioneer, he fully acknowledged the work done in plant physiology by Mayow, Grew and Malpighi. His views regarding the transpiration of plants and their nourishment, and how they utilized some constituent of the atmosphere only under the influence of solar light, were all in advance of his time.

In animal physiology he was also a pioneer, for he was the first to ascertain the magnitude of the pressure of the circulating blood: this he did by opening the left crural artery of a living animal, the horse. His method was crude: he merely allowed the blood to rise as high as it could (8 ft. 3 in.) in a vertical tube partly of brass and partly of glass; but the principle of his method is even now most fruitfully used in practical medicine. He studied the general physiology of the blood-pressure in arteries and in veins, as also the force and output of the

[1] Cf. "Vegetable Statics," Vol. I., p. 265.

left ventricle, acknowledging, however, previous work by Harvey, Lower, Borelli, Pitcairne, Keill and others. As became every physiologist of his time, he wrote on the "animal spirits" and on the "sympathy" between the nerves; he studied experimentally the physics of respiration; he produced pneumo-thorax in the dog, and speculated on the sources of animal heat, agreeing with Boerhaave and the iatro-physical school in attributing it to friction of the blood and blood-cells against the walls of the vessels. He tried to explain the florid nature of arterial blood, but on this point he was not so enlightened as his predecessor Lower about sixty years before. He used the microscope in an interesting way to try to gain information as to the cause of muscular contraction in the living frog. He incidentally saw the red blood corpuscles in the living capillaries and noticed that the diameter of the smallest vessel was equal to that of the blood-disc. He gives the receipt of an injection-fluid for blood-vessels. He continued Harvey's work, by studying the rupturing pressures in blood-vessels and the rupturing strain of various animal fibers. He speculated on the physiology of renal secretion.

In what would now be regarded as pure medicine and even surgery, Hales was just as active. He wrote critically on the therapeutic value of "tar-water"; he wrote on fevers and on the possible effects of fever heat on the blood, actually suggesting that the shivering fit of ague might be due to the too thick blood not passing with ease through the capillaries. He studied the effect of alcohol on the living organism by injecting brandy into the blood-vessels of the dog. He wrote on paracentesis abdominis. Hales spent a great deal of time in attempts to discover satisfactory solvents for stone in the bladder and the kidneys, and actually devised a method of extracting stone from the bladder.

In the physical sciences he wrote on earthquakes, and he invented an instrument for determining the depths of the ocean: this appears to have been of some practical service, but, according to one account, was lost in the West Indies. Hales invented a method for the dredging of harbors. He gives directions for "salting" meat for long voyages.

Hales, as we have seen, was patronized by Frederick, Prince of Wales, the eldest son of George II., who died before his father in 1751. His widow Augusta, daughter of Frederick, Duke of Saxe-Gotha, for the last ten years of Hales's life the Princess Dowager of Wales, had a great regard for the Reverend Doctor, and there is no doubt that had he so desired it, he might have become a bishop. The utmost he would allow, refusing a canonery of Windsor, was to be made "Clerk of the Closet" or almoner "to the Princess Dowager." After his death, the Princess erected a mural monument in marble to his memory in Westminster Abbey. He is not buried there amongst England's other great ones, but under the tower of his old church at Teddington. The memorial is wrought in *alto relievo;* it represents the figures of Religion

and Botany supporting a medallion of the philosopher beneath which is a globe with the winds portrayed on it in allusion to Hales's invention of ventilators. The laudatory inscription is in Latin verse, a translation of which I am enabled to give through the kindness of Professor Wallace Lindsay, LL.D., of the chair of Latin at the University of St. Andrews.

> To the Reverend Doctor Stephen Hales,
> Augusta, mother of good George III,
> Erected this monument.
> She selected him for her chaplin.
> He died, January 4th, 1761.

> At Hales' tomb which Augusta caused to rise with gleaming stone and to have due beauty, Piety and grey haired Faith and supreme Virtue, a sacred band, drop constant tears; while above the dead prophet divine Wisdom proclaims, "He was skilled in helping men's troubles, he too in tracing God's works. No lapse of time will weaken your praise, great Hales, or your titles! England is proud to enroll you amongst her noblest sons, England who can boast a Newton"!

This is interesting as being almost a contemporary estimate of Hales. His medical work and researches as a sanitarian are evidently alluded to in the phrase "helping men's troubles"; his more purely scientific work being alluded to in "tracing God's works." Sir James Edward Smith, the physician and naturalist, said "his philosophy was full of piety."

Seeing that the stone over the grave of Hales has done duty as one of the flag-stones of the porch of the old church of St. Mary's, Teddington, for more than 150 years, it is not surprising to find that its inscription is now almost entirely worn away. In January, 1911, a number of English botanists unveiled a tablet on the wall of the porch of the tower which they caused to be inscribed as follows:

> Beneath is the grave of Stephen Hales. The epitaph now partly obliterated but recovered from a record of 1795 is here inscribed by the piety of certain botanists A.D. 1911. "Here is interred the body of Stephen Hales, D.D. clerk of the closet to the Princess of Wales, who was minister of this parish 51 years. He died 14th of January, 1761, in the 84th year of his age."

One of the few redeeming features in the character of Frederick, Prince of Wales, was his friendship for Hales. It is not very far from where the Prince lived at Kew to where Hales worked at Teddington, and so H. R. H. would frequently drop in and watch the scientific clergyman surrounded by his pressure-gauges, bellows and crucibles.

Another, and much more distinguished neighbor of Hales, was the poet Pope with whom he seems to have been pretty intimate. Certain it is that the Reverend Doctor was one of the three witnesses to the will of the wicked wasp of Twickenham dated December 12, 1743.

Pope alludes to Hales as "plain Parson Hale" in the second of the moral essays (the poem is "Epistle II. To a lady: of the characters of women"). The lines are:

Alas! I copy, or my draught would fail,
From honest Mahomet or plain Parson Hale.

I confess I don't know what this means, but one can see a very unwarrantable liberty taken with Hales's name. The poet's own note on this is:

Dr. Stephen Hale not more estimable for his useful discoveries as a natural philosopher than for his exemplary life and pastoral charity as a parish priest.

Pope, however, has left it on record that he highly disapproved of the doctor's vivisectional experiments. Peg Woffington, the actress, was for a time a parishioner of Hales.

We strongly suspect that the theology of Hales was ponderous and his religious discourses dull. Absolutely correct as regards the sex morality of his own life, he appears to have dealt pretty severely with any erring members of his flock, for there is extant a list of names of women whom he made do public penance in church in a manner more resembling the custom amongst the strictest of the Scottish Covenanters than that of English Episcopalians.

At least one sermon that Hales delivered has come down to us, because it was published as the anniversary sermon preached before the Royal College of Physicians in the church of St. Mary-le-Bow on September 21, 1751. It is now a rare pamphlet, entitled "'The wisdom and goodness of God in the formation of man,' preached according to the institution of Dr. Crowne and his widow, the Lady Sadler, by Stephen Hales, D.D., F.R.S., Clerk of the Closet to Her Royal Highness the Princess of Wales." It is so full of curious anatomical and physiological allusions that it reads far more like a lecture in natural history than what we should consider a sermon. Another sermon preached by Hales in 1734 has come down to us. His text was Gal. VI., v. 2, the audience the trustees of the colony of Georgia, for Hales was one of the trustees of this newly founded colony (1733).

Another of Hales's neighbors was the dilettante, Horace Walpole, who lived near by at Strawberry Hill; he wrote cynically of Hales as a "poor, good, primitive creature." A far better judge, the physiologist Haller, declared that Hales was "pious, modest, indefatigable and born for the discovery of truth."

Hales must have been modest, for there are very few references to him in contemporary literature. He is not once mentioned in the chapter on Science in Ashton's "Social life in the reign of Queen Anne." By his scientific peers, however, his worth was fully recognized. In 1726 the University of Oxford conferred on him the degree of D.D. The Royal Academy of Sciences at Paris in 1753 elected Hales one of the eight foreign members in the room of Sir Hans Sloane, Bart: deceased.

The botanist, John Ellis, named a genus of plants, *Halesia,* in honor of him.

Hales's portrait was painted by Thomas Hudson (1701–1779), an English artist who had the honor to have Reynolds for a pupil. The monument in the Abbey is by Wilton who executed Wolfe's in the same sanctuary.

One of the most scholarly accounts of Hales is from the pen of Professor Percy M. Dawson, M.D.

To arrive at any definite ideas as regards Hales's views on his own times or on the society of his day is very difficult, since almost all that we know of him is in an exclusively scientific environment. Seeing that his patrons were the Prince and Princess of Wales and that he was quite intimate with the Duke of Cumberland, he could hardly have been other than an ardent Hanoverian. From all that we have to judge by, Hales's personal tastes harmonized with the Georgian Philistinism around him, for he is reported to have removed a beautiful east window in the church at Teddington, substituting for it something of greatly inferior beauty.

Hales lived through a period that was by no means destitute of incident; it included the Handel-Buononcini controversy, the Jacobite Rising, the quarrels of George II. with his eldest son, the battles of Dettingen and Fontenoy, the failure of the great attack on Carthagena (1741), the development of Britain's resources under the peaceful administration of Sir Robert Walpole, the commencement of the vigorous rule of William Pitt the elder, Wolfe's magnificent achievement on the Heights of Abraham, Clive's crushing of Surajah-Dowlah at Plassey, the reform of the calendar and the preaching of Wesley.

Pope, Gay, Young, Thomson, Cowper, Johnson, Gray and Collins in literature; Hogarth, Gainsborough and Sir Joshua in art, Handel in music, and Sir Hans Sloane in science are the names of honorable mention during the life-time of the Rev. Dr. Hales.

While we congratulate ourselves on having attained to an understanding of the principles of ventilation, on having abolished typhus fever from our hospitals, prisons and ships, on having devised apparatus for sustaining life in irrespirable and deadly atmospheres, let us never forget that the initial stages in the comprehension of these things were worked out not by any high-placed, well-paid, public official, but by a modest amateur, the scientifically minded, country clergyman, Stephen Hales.